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Solar fundamental pulsation and the origin of the long period Alfvén waves observed in the solar wind

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Abstract. *Ulysses* spacecraft discovered the long-period, outwardly propagating Alfvén waves in the solar polar regions (Balogh *et al.* 1995). Here we suggest that the waves may be generated in the solar interior due to the pulsation of the Sun in the fundamental radial mode or in low-frequency g-modes. The period of fundamental mode is about 1 hour, while the period of g-modes can be longer. The pulsation causes a periodical variation of density and large-scale magnetic field, this affecting the Alfvén speed in the solar interior. Consequently the Alfvén waves with the half frequency of pulsation (i.e. with the double period) can be parametrically amplified in the interior below the convection zone due to the recently suggested swing wave-wave interaction. Therefore the amplified Alfvén waves have periods of several hours. The waves can propagate upwards through the convection zone to the solar atmosphere and cause the observed long-period Alfvén oscillations in the solar wind.

Keywords. Sun: interior, Sun: solar wind, Sun: oscillations

1. Introduction

Recent *in situ* observations of solar polar regions by *Ulysses* spacecraft have shown the presence of long-period (periods of several hours) outwardly propagating Alfvén waves (Balogh *et al.* 1995). As the observed Alfvén waves show predominantly outward propagation, they probably are of solar origin.

Here we suppose that the long-period Alfvén waves can be generated in the solar interior by pulsation either in the fundamental radial mode and/or in low frequency g-modes through the recently suggested *swing wave-wave interaction* (Zaqarashvili & Roberts 2002). The generated Alfvén waves may propagate upwards and cause the observed oscillations in the photosphere/chromosphere and the solar wind.

2. Fundamental pulsation of the Sun

Solar radial adiabatic pulsations can be represented as standing spherical waves with a linear radial velocity field

$$u_r = \alpha F(r)\sin(\omega_n t), \qquad (2.1)$$

where ω_n is the eigenfrequency, $F(r)$ is the eigenfunction and α is the pulsation amplitude. The fundamental mode of solar oscillation has the period of ~ 1 hour.

The radial pulsation leads to local periodical variation of density and magnetic field throughout the Sun, which causes the periodical variation of the Alfvén speed at each level r.

3. Resonant torsional Alfvén waves in the solar interior

In the presence of the radial pulsation (2.1) the temporal dynamics of Alfvén waves is governed by Mathieu equation (Zaqarashvili & Belvedere 2005) as

$$\frac{\partial^2 \tilde{u}_\phi}{\partial t^2} + \left[v_A^2 k_z^2 + \frac{\alpha \Psi(r)}{\omega_n} \cos(\omega_n t) \right] \tilde{u}_\phi = 0, \tag{3.1}$$

where v_A is the Alfvén speed and k_z is the wavenumber of Alfvén waves. This equation has the main resonant solution when (Zaqarashvili & Roberts 2002) $\omega_A = v_A k_z \approx \omega_n/2$, where ω_A is the frequency of torsional Alfvén waves.

Thus the radial pulsation leads to an exponential amplification of torsional Alfvén waves with the half frequency $\omega_n/2$. The growth rate depends on the amplitude α and spatial structure of the pulsation eigenfunction $F(r)$, which in turn depends on the radial structure of density ρ_0 and magnetic field B_0.

As the main resonance occurs at the half frequency of pulsation, the resonant Alfvén waves in the solar interior will have a period $T_A = 2T_0 \approx 2$ hours, where $T_0 \approx 1$ hour is the pulsation period. Due to the resonant width of equation (3.1), the period of generated Alfvén waves may be in the range of $T_A \sim 1.5 - 3$ hours.

The amplified Alfvén waves can propagate along the magnetic field lines through the convection zone (mainly in sunspots and in regions between large convective cells, where the magnetic field is predominantly large scale) and reach the solar atmosphere. Low-frequency transversal oscillations have been observed in photosphere, chromosphere and prominence with the period of ~ 1.75 hours at sunspot (25^0-30^0) and higher (60^0) latitudes (Mashnich & Bashkirtsev(1999)). Also long-period transversal oscillations with the period of ~ 2 hours have been observed in chromospheric spectral lines (Merkulenko *et al.*(1988)) and again can be interpreted as Alfvén waves. It is the fact that long-period Alfvén waves are observed by *Ulysses* (Balogh *et al.* 1995) in fast solar wind at high latitudes where dipolar magnetic field component is dominant.

4. Conclusions

We suggest that outwardly propagating long-period Alfvén waves, which have been observed in solar polar regions by *Ulysses* (Balogh *et al.* 1995) can be generated in the solar interior due to solar pulsation in fundamental radial mode and also in low-frequency g-modes. The radial pulsation parametrically amplifies torsional Alfvén waves with the double period. Although the process has a resonant range of frequencies, whose width depends on the amplitude of pulsation. Therefore the solar fundamental radial pulsation, with a period of ~ 1 hours, will amplify Alfvén waves with a period of ~ 1.5-3 hours. Solar g-modes will excite the Alfvén waves with longer period. These amplified Alfvén waves may propagate upwards to the solar corona and cause the observed magnetic field and velocity oscillations in the solar wind.

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